Healthy Lake Huron – Clean Water, Clean Beaches

Southeastern Lake Huron Tributary Water Quality Synthesis and Modelling (October 2010 to September 2015)

Prepared for: Environment Canada

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March 31, 2016

Acknowledgements:

Alec Scott provided coordination amongst agencies for the collection of water quality and quantity data. Water monitoring staff at the different conservation authorities included: Jo-Anne Harbinson, Shaun Anthony, Mat Shetler, Chris Van Esbroeck, Tom Skinner, Abbie Gutteridge, Jessica Van Zwol, and Girish Sankar. The authors would like to acknowledge the technological and technical expertise provided by Mark Lowenstine. His ongoing commitment to trouble-shooting ISCOs and other field equipment and data crunching has been invaluable. GIS expertise has been provided by Tracey McPherson. Water quality analysis was provided by the Ministry of the Environment and Climate Change, with Pradeep Goel and Scott Abernethy ensuring that adequate laboratory allocation resources were provided. Funding for data collection has gratefully been provided through the Ministry of the Environment and Climate Change, Ontario Ministry of Agriculture, Food and Rural Affairs, and Environment Canada. The views expressed in this report are the views of the authors and do not necessarily reflect those of the funding support agencies.

Project Background

The nearshore area of the Great Lakes provides many residents of Ontario with drinking water and recreational opportunities. However, nutrient, sediment, and bacterial impacts have increasingly limited both the human uses and the ecological integrity of these nearshore waters (Smith *et al.* 2015). For example, in 1977, algae were observed as a thin coating at relatively few beaches along the southeast shore of Lake Huron. By 2007, almost all rocky portions of the lake-bed at these same sites were covered by algae (Barton *et al.* 2013). Large and localized accumulations of algae have been washing up on shore and causing odor problems from decaying algal mats.

The Great Lakes Water Quality Agreement (2012) Lakewide Annex states that Canada and the United States will assemble, assess, and report on existing scientific information concerning the state of the waters of each Great Lake including current and future potential threats to water quality. Further, the Canada-Ontario Agreement Respecting the Great Lakes commits agencies to improve the knowledge and understanding of nutrient concentrations and loads in Great Lakes tributary discharges.

A multi-stakeholder program known as the Healthy Lake Huron – Clean Waters, Clean Beaches Initiative is coordinating efforts to ensure that beaches and nearshore areas along the southeast shore are safe and clean. Currently, partners are coordinating actions to implement agricultural best management practices that are aimed at lowering the amount of phosphorus entering Lake Huron in five key watersheds (Figure 1). Monitoring of water quality in the priority watersheds is being coordinated by four conservation authorities (conservation authority name is in parentheses):

- Pine River sub-watershed – South Pine River (Saugeen Valley Conservation Authority);
- North Shore sub-watershed – Garvey Creek/Glenn Drain (Maitland Valley Conservation Authority);
- Bayfield North sub-watershed – Gully Creek (Ausable Bayfield Conservation Authority);
- Main Bayfield watershed – Trick's Creek (Ausable Bayfield Conservation Authority); and
- Lambton Shores tributaries in Lambton County – Shashawandah Creek (St. Clair Region Conservation Authority).

Report Objectives and Format

This report is a summary of different approaches to evaluate water quality data collected from the priority watersheds along the southeast shore of Lake Huron. The objectives of the project were to:

1) analyze data for each of the priority streams to better understand the relationship between discharge (stream flow) and concentration under different seasonal scenarios;
2) compare three water quality models (simple models that quantify the relationship between discharge and concentrations) for calculating loads;
3) calculate annual loads for the five priority streams (October 2012 – September 2015 data) with the preferred water quality model to compare loads over time and across watersheds; and
4) examine the relationship between land management decisions and nutrient loads by exploring process-based hydrologic models (models that incorporate climate, soil, slope, and land use) to calculate annual loads.

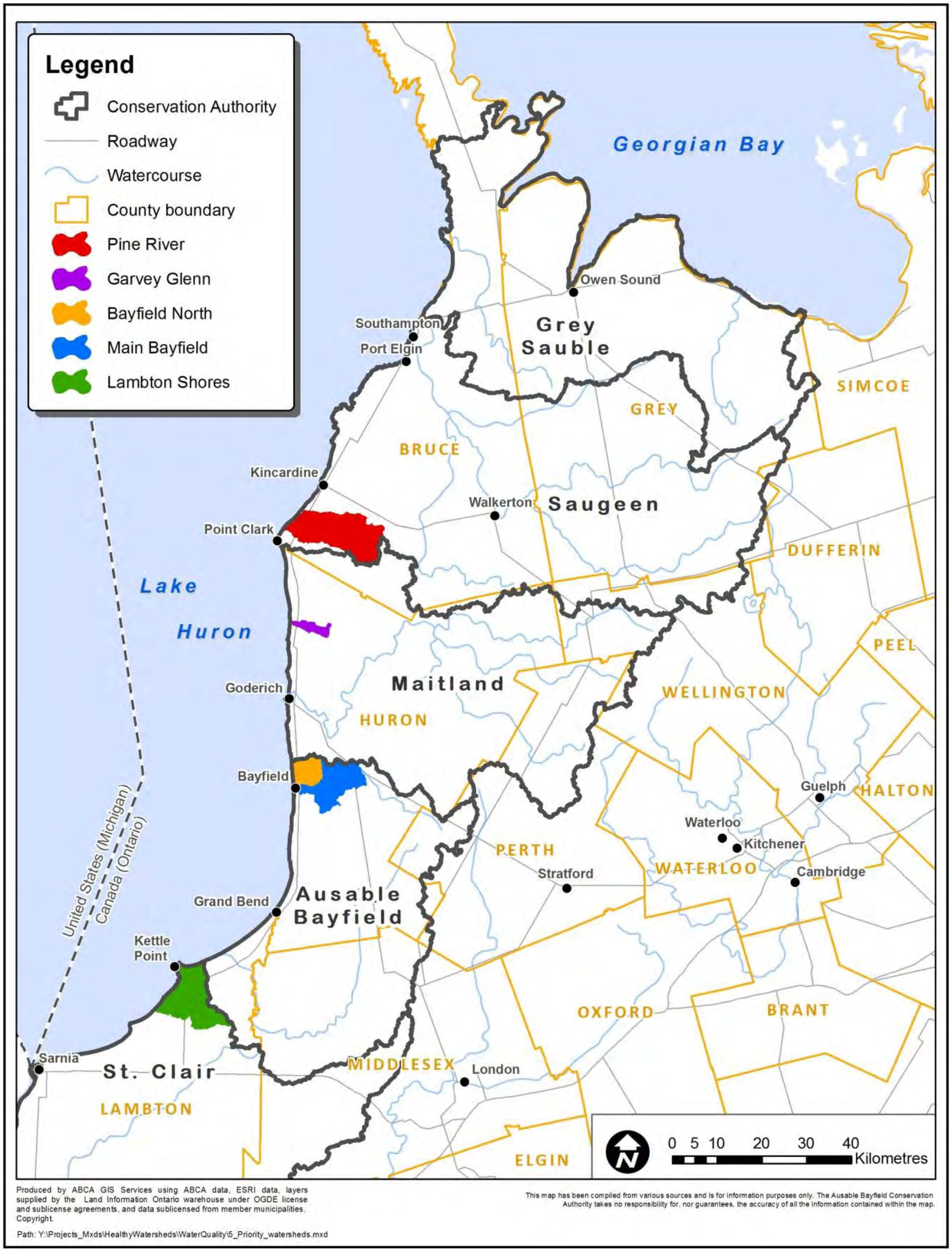

Figure 1: Location of the five priority watersheds in the Healthy Lake Huron – Clean Waters, Clean Beaches Initiative.

To address these project objectives, the remainder of the report is organized into three sections:

1) Methods;
2) Results and Discussion, including:
    a. A comparison of various load estimation models and output from two process-based hydrologic models,
    b. An analysis of spatial and temporal patterns in water quality indicators, and
    c. A seasonal regression analysis of stream flow and pollutant concentrations; and
3) General conclusions and next steps.

Methods

Site Selection

The five Lake Huron watersheds are small and mostly drain agricultural landscapes (Table 1). A more complete description of the watersheds can be found in other reports (Emmons & Olivier Resources, Inc. *et al.* 2014, LaPorte *et al.* 2012, King *et al.* 2014, Brock *et al.* 2010, Schnaithmann *et al.* 2013, Van Zwol *et al.* 2012). Water quality monitoring stations were selected to be as far downstream as possible in the watershed, but remaining outside of the lake-effect zone. Stations were co-located with reliable flow gauging stations so that water quality results could be combined with stream discharge measurements for the computation of loads (see Appendix A for maps of the study watersheds and sites).

Table 1: Watershed size and land use (based on 2013 cropping year) upstream of sampling location in each study sub-watershed.

Sub-watershed	Size (ha)	Corn (%)	Soya Beans (%)[A]	Winter Wheat (%)	Other Crops (%)[B]	Hay/ Pasture (%)	Natural/ Roughland (%)[C]	Other (%)[D]
South Pine River, upstream of Ripley gauge	2788	24.1	23.3	13.5	11.6	10.5	14.0	3.0
Garvey Creek/Glenn Drain, at Kerry's Line gauge	1286	28.0	39.3	10.7	4.7	2.2	11.4	3.7
Gully Creek, at Porter's Hill Line gauge	1040	20.7	31.4	19.0	0.0	3.7	20.7	4.4
Trick's Creek, at Bayfield Road gauge	2116	24.4	21.5	9.5	0.8	7.9	16.9	19.1
Shashawandah Creek, upstream of Kinnard Road	2681	20.2	31.5	18.9	8.6	4.9	11.9	4.0

[A] Included soya and edible beans.
[B] Included agricultural fields where the crop type was listed as unknown or was another crop including spring cereals, canola, and vegetables.
[C] Included riparian corridors, ditches, scrub land, woodlands and wetlands.
[D] Included urban land, roads, pits, farmsteads, farm access roads, and ponds.

Water Quantity Monitoring

Water level (also referred to as water stage) data were collected every five minutes at all stream gauges except for the Pine River stream gauge, which collected data every fifteen minutes. A WaterLOG H-3553 Compact Combo Bubbler System was used to measure water stage, with a twelve-volt, 100-amp-hour valve-regulated lead acid battery and solar panel providing power, and an FTS Axiom H2 Datalogger logging and transmitting data through a Geostationary Operational Environmental Satellite (GOES) antenna. This continuous record of stage was translated to stream discharge by applying a stage-discharge relationship (also called a rating curve). A stage-discharge relationship was developed for each stream gauge by measuring the flow of the stream with a flow meter (Marsh-McBirney Flo-Mate™ Model 2000). For each measurement of discharge there is a corresponding measurement of stage. High and low stages and flows are particularly important for the development of the rating curve; however, it was unsafe to obtain manual measurements of flow in the streams when they were in peak-flow conditions. Instead, a theoretical equation related to the shape, size, slope, and roughness of the channel at the stream gauge was used to iteratively determine the stage-discharge relationship at higher stages and flows. This relationship differs between stream gauging stations and can also change over time at a specific station. More details on the water quantity monitoring methods can be found in Upsdell Wright *et al.* 2015a.

Water Quality Monitoring

Many water quality monitoring programs involve a random sampling strategy, whereby samples are collected on pre-determined days of the month. However, rain, rain-on-snow, and snowmelt events (herein referred to as events) are important because high concentrations of some pollutants, particularly sediment and phosphorus, are transported during these events (Upsdell Wright and Veliz 2013). The monitoring and modelling results in the Watershed Based Best Management Practices Evaluation study found that intermittent channels that form across the land contribute to poor water quality during storm events (Simmons *et al.* 2013). Further, practices to address rural water quality nutrient enrichment issues are undertaken to reduce the formation and/or the effects of these intermittent channels on the landscape. To understand the effectiveness of watershed plans and rural best management practices (BMPs) on water quality, it is imperative to collect *event data* prior to and after the establishment of the watershed plans and BMPs. Therefore, water quality monitoring for this study included sample collection when water was running across the landscape in order to improve the accuracy of pollutant load estimates.

For the purposes of this study, water samples were collected year-round under both low-flow and high-flow conditions. Richards (1998) has shown that the 80th percentile of flow is an appropriate division for separating runoff events from low-flow periods for Lake Erie tributaries in Northwest Ohio. This study used the same approach. Continuous flow data from October 2012 to September 2015 were used to establish the low-flow conditions. A threshold was set at the 80th percentile of the continuous flow record for each of the sites to separate low flow from event flow. Low-flow grab samples were collected monthly between October 1, 2012, and September 30, 2015. High-flow events were sampled with an ISCO® 6712 automated sampler at each of the five stations. The ISCO samplers were set to trigger with a rise in water level and to collect samples throughout the hydrograph, attempting to capture samples at the onset of the event, mid-way up the rising limb of the hydrograph, at the peak, mid-way down the falling limb, and at the end of the event.

Water samples were primarily analyzed for nutrients and suspended solids by the Ministry of the Environment and Climate Change (MOECC) laboratory in Etobicoke; however, on occasion, samples were submitted for analysis to ALS Laboratory in Waterloo. There are different analytical approaches to estimating the bioavailable forms of phosphorus. In this study, phosphate-phosphorus was measured.

Approximately 1500 tributary water quality samples were collected between October 1, 2012, and September 30, 2015. An additional 245 water quality samples were collected in Gully Creek between October 1, 2010, and September 30, 2012.

In the three-year period (2012 to 2015), all of the watersheds had more than 40 events (Table 2). Gully Creek had 82 events, whereas only 42 events were documented in the Garvey Creek/Glenn Drain. Not all events were sampled. Some events were missed due to decisions made *a priori* about the size of the event, equipment malfunctions, and staffing issues (*i.e.,* holidays and other work priorities).

Table 2: Number of storm events and water quality samples in Healthy Lake Huron priority watersheds (October 2012 to September 2015).

Watershed	Total Number of Events	Number of Events Sampled	Total Number of Samples	Number of Event Samples
South Pine River*	51	12	121	100
Garvey Creek/Glenn Drain*	42	25	294	196
Gully Creek	82	41	455	319
Trick's Creek	74	44	360	249
Shashawandah Creek*	49	21	264	173

* Incomplete flow record for 2013 water year.

A more detailed account of the field methods for monitoring water quality is provided in Upsdell Wright *et al.* 2015a.

Pollutant Load, Mean Concentration, and Export Coefficient Calculation

For this report, both the annual flow-weighted mean concentrations and the loads have been summarized. Dickinson (in Upsdell Wright *et al.* 2015b) suggested that, if the focus of the study is on concentration targets or standards, then concentration values are needed. However, if the focus of the study is on land use management or Great Lakes impacts, then load estimates are needed. Past water quality reports completed by the Ausable Bayfield Conservation Authority have reported findings as concentrations (see http://www.abca.on.ca/publications.php for past reports). However, calculating loads is important for comparing the contributions that are made from the different watersheds to Lake Huron.

Water quality indicator concentrations (nitrate-nitrogen plus nitrite-nitrogen, phosphate-phosphorus, total phosphorus , and total suspended solids) from the grab and ISCO samples collected during the study period were converted to loads (mass per time), flow-weighted mean concentrations (FWMC) (mass per volume), and export coefficients (mass per watershed area). These computations help to remove the variability associated with event discharge and watershed size.

Loads are the product of stream flow (volume per time) and concentration (mass per volume). A mass load (Equation 1) is a calculation of the total mass of a substance, usually expressed in kilograms, that is transported past a particular point on a stream or river over a given time period, often annually (Cooke 2000). In this study, annual loads were calculated (including events and low-flow periods).

Equation 1

Mass Load (kilograms) $=\sum c_i q_i t_i$

where

i = 1 to n (number of samples)
c_i = sample concentration (milligrams per litre)
q_i = instantaneous stream flow (litres per second)
t_i = time interval (seconds)

In a flow-proportionate sampling program, an individual water sample does not characterize the event or low-flow period. To estimate the average concentration, each sample must be weighted to represent a particular portion of the hydrograph (Equation 2) (Cooke 2000). Flow-weighted mean concentrations are concentrations that are adjusted for stream flow over a given period – in this study, the length of the water year. This computation allows for comparisons between streams with different flows or the same stream at different times.

Equation 2

Flow-Weighted Mean Concentration (milligrams per litre) = $\frac{Mass\ Load\ (kilograms)}{Total\ Stream\ Flow\ Volume\ (litres)} \times 1000$

The total mass export coefficient or unit-area load (Equation 3) is an estimate of the amount of the constituent that is lost per hectare of watershed for the given time period.

Equation 3

Mass Export (kilograms per hectare) = $\frac{Mass\ Load\ (kilograms)}{Watershed\ Area\ (hectares)}$

Reference Load Calculation

Continuous records of both stream flow and concentrations are needed to calculate loads. Since the concentrations of pollutants are not typically monitored continuously, load-estimation methods are used to calculate loads. Generally, there are five types of load-estimation methods: averaging, numeric integration, ratio, regression, and interpolation (Richards 1998). Averaging techniques determine load based on multiplying the average concentration by the average flow over a period of time. Numeric integration involves multiplying a concentration by the total flow over a period of time and then summing the time intervals (*e.g.*, Equation 1). Ratio estimators determine load by multiplying the mean daily load by a flow ratio (derived by dividing the average flow for the period of interest by the average flow for the days on which water quality samples were collected). A total load is then calculated by multiplying the adjusted load by 365 days. Regression approaches determine load based on fitting a relationship between flow and concentration. Finally, an interpolation approach assumes a linear relationship between consecutive measured concentrations, which are then multiplied together with flow over a period of time.

Water quality data and flow measurements from the GULGUL5 station in Gully Creek were used to calculate a reference load for each water quality indicator with a numeric integration method (Equation 1). The GULGUL5 station (Appendix A) was chosen for this analysis because it has reliable flow and exhaustive water quality sampling records, particularly for the 2013 water year (October 1, 2012, to September 30, 2013).

A total of 188 water quality samples were collected from the GULGUL5 station between October 1, 2012, and September 30, 2013. Low-flow grab samples were collected up to once per month (n = 11). High-flow events were sampled with the ISCO automated sampler (n = 177). Water samples were analyzed for nitrate-nitrogen plus nitrite-nitrogen (nitrate-N + nitrite-N), phosphate-phosphorus (phosphate-P), total phosphorus (TP), and total suspended solids (TSS).

To determine annual pollutant loads, mass loads were estimated for storm events and low-flow periods that were not sampled. In this study, gaps in data were estimated following methods developed by Stuntebeck *et al.* (2008), in which concentrations were substituted from similar storm events and low-flow periods that were sampled during similar time periods. Up to 58 water quality samples were used to fill in unsampled gaps. The annual load was then determined by summing loads for sampled and unsampled events and low-flow periods.

Load Estimation Modelling

Once a reference load was calculated, it was compared against results from three load estimation models (Water Quality Analyser, FLUX32, and Water Information Systems KISTERS) to select a preferred one. By performing this comparison, the process for calculating future loading values reliably could be streamlined. Output from two complex process-based hydrologic models, including the Soil and Water Assessment Tool (SWAT) and the Personal Computer Storm Water Management Model (PCSWMM), were also used to compare loading estimates.

Five loading estimation software tools that were used in this report are detailed below. Load Estimator (LOADEST), a program for estimating constituent loads in streams and rivers with regression models, was not included in this report due to the level of effort involved in managing large data sets. The data sets used for this study required substantial manipulation of the data to format them for input to LOADEST.

Water Quality Analyser

Water Quality Analyser (WQA), developed by eWater Source in Australia, was designed to monitor in-stream water quality and estimate pollutant loads. The software estimates loads and flow-weighted mean concentrations using a variety of averaging, integration, ratio, regression, and interpolation methods (see Appendix B). Sample concentration data were matched to the nearest five-minute flow interval in Microsoft Excel and reconciled into WQA. Water Quality Analyser was then given instructions to calculate annual loads (in kilograms) or flow-weighted mean concentrations (in milligrams per litre) by nine different loading algorithms. Software version 2.1.2.4 was used for this report.

FLUX32

FLUX32, developed by the United States Army Corps of Engineers, was designed to estimate the transport of water quality indicators past a tributary sampling station over a given period of time. The software estimates loads and flow-weighted mean concentrations using a variety of averaging, integration, ratio, and regression methods (Appendix C). Sample concentration data were matched to the nearest five-minute flow interval in Microsoft Excel and reconciled into FLUX32. FLUX32 only accepts daily flow and/or sample data (*i.e.*, one sample per day); however, flow data in Gully Creek were recorded in five-minute intervals. To circumvent this issue, each five-minute flow interval was assigned an arbitrary corresponding date. For instance, a date and time of "12Feb2012 07:05" was converted to "04/30/1984" in FLUX32, "12Feb2012 07:10" became "05/01/1984" and so on. FLUX32 was then given instructions to calculate annual loads (in kilograms) or flow-weighted mean concentrations (in milligram per litre) by six different loading algorithms. Software version 3.37 was used for this report.

Water Information Systems KISTERS (WISKI)

WISKI, developed by KISTERS in California, is a water data management tool that stores continuous flow and sample concentration data. WISKI does not inherently contain any loading estimation algorithms; however, a variety of algorithms can be entered manually. WISKI was given instructions to calculate annual loads (in kilograms) by linearly interpolating gaps in the sample concentrations and summing the product of the interpolated concentrations and flow. A mass load was then estimated by referring to a cumulative frequency graph of loads. Software version 7.4 was used for this report.

Soil and Water Assessment Tool (SWAT)

The SWAT is a hydrologic process-based model developed jointly by the United States Department of Agriculture and Texas A&M University. It can be applied to small watersheds or larger river basins to simulate the quantity and quality of surface and ground water, and predict the environmental impacts of land use, land management practices, and climate change. The SWAT may also be used in assessing soil erosion prevention and control, non-point source pollution control, and regional management in watersheds. For this study, sediment and nutrient yields were calculated using SWAT.

Personal Computer Storm Water Management Model (PCSWMM)

A Rural Stormwater Management Model (RSWMM) was previously developed for each of the priority sub-watersheds with PCSWMM (Emmons & Olivier Resources Inc. *et al.* 2014). PCSWMM is an urban stormwater management system and modeling package, used to support spatial decision-making. It was developed by Computational Hydraulics International (CHI) in Guelph, Ontario. PCSWMM is a continuous simulation, watershed-scale (5 to 2000 hectares) model that simulates urban runoff quantity and quality from different sources. Geographic Information Systems (GIS) have been integrated into the model's design, enabling the assessment of a variety of scenarios, such as changes in land use and climate. For this study, sediment and nutrient yields were calculated using PCSWMM.

Uncertainty Analysis

An uncertainty analysis was performed to determine the relative difference between the GULGUL5 station's reference load for each water quality indicator and the loads estimated by the software tools.

The uncertainty was calculated as the percentage difference between the estimated load and the reference load (Equation 4).

Equation 4

$$Difference\ (per\ cent) = \left(\frac{Estimated\ Pollutant\ Load - Reference\ Pollutant\ Load}{Reference\ Pollutant\ Load}\right) \times 100$$

Spatial and Temporal Analysis

Loads are typically calculated annually and based on a water year (*e.g.*, October 1 to September 30). The United States Geological Survey uses a water year with an October 1 start date, as it is the time of year least likely to have major storm events on either side of that date. Use of this date is thought to avoid inflating or reducing the overall load for that year due to variations in major discharge events. For the purposes of the current study, to better understand baseline water quality conditions in the five watersheds along the southeast shore of Lake Huron, mass load, flow-weighted mean concentration, and mass export values were calculated for the period between October 1, 2010, and September 30, 2015. Water quality was analyzed for nitrate-nitrogen (nitrate-N), phosphate-phosphorus (phosphate-P), total phosphorus (TP), and total suspended solids (TSS).

Seasonal Regression Analysis

Annual pollutant transport is typically defined by seasonal changes, in which greater loads occur during large, infrequent storm events (usually during winter and spring) and smaller loads occur during smaller, more frequent storm events and low-flow periods (usually during fall and summer). It is not surprising that 80 to 90 per cent of total loads occur during only 10 to 20 per cent of the time (Richards 1998). To investigate the seasonality of flow and pollutant transport, Pearson's linear correlation equation was applied to each of the five priority sub-watersheds, during each season of the study period. Pearson's correlation was determined using a regression function in Microsoft Excel 2010. Correlation values were separated into four categories: strong correlation between flow and pollutant concentration ($R^2 = 0.7 \leq x \leq 1.0$); moderately strong correlation ($R^2 = 0.5 \leq x \leq 0.7$); moderately weak correlation ($R^2 = 0.3 \leq x \leq 0.5$); and weak correlation ($R^2 = 0.0 \leq x \leq 0.3$). Seasons were defined as winter (January-March), spring (April-June), summer (July-September), and fall (October-December).

Results and Discussion

Load Estimation Model Comparison

The total annual mass loads (or reference loads) calculated for the 2013 water year in Gully Creek are detailed in Table 3. The reference loads were compared against 17 different load estimation methods from four software tools (Table 4). Averaging techniques tended to overestimate reference loads by three to thirteen times, while the Beale ratio method performed poorly for three of the four water quality indicators (phosphate-P, TP, and TSS). These techniques likely failed to estimate loads within a reasonable amount of uncertainty due to the frequency with which higher flows were sampled. Some regression and integration techniques performed reasonably well by estimating the load to within 20 per cent of the reference load. The results from the hydrologic process models were variable. For instance, PCSWMM performed adequately for all water quality indicators, except TP (Table 4), while values from the SWAT were consistent with estimates from WQA for all water quality indicators, except TSS (Appendix D).

The Linear Interpolation method in WQA software estimated mass loads to within 10 per cent of the reference load for all water quality indicators (Table 4). In addition, the interpolation technique had the lowest combined average deviation from the reference load (Mean of the Differences = 5%, Standard Deviation = 3%). A linear interpolation method was also found to accurately estimate loads in small tile-drained watersheds in Ohio and Southwestern Ontario (Williams *et al.* 2015).

From a practicality perspective, WQA was more efficient and simpler to use than either FLUX32 or WISKI. With this data set, the Linear Interpolation method in WQA was best suited to calculate loads in the priority watersheds for further analysis in this report.

Table 3: Total reference load estimates for four water quality indicators at GULGUL5 station in Gully Creek (October 1, 2012 – September 30, 2013). Note: NO_{32}-N is nitrate-nitrogen + nitrite-nitrogen, PO_4-P is phosphate-phosphorus, TP is total phosphorus, and TSS is total suspended solids.

Sample Condition	Time Period	NO_{32}-N (kg)	PO_4-P (kg)	TP (kg)	TSS (kg)
Low flow[1]	Oct 1-13, 2012	43.5	0.1	0.2	20.6
Event[2]	Oct 13-23, 2012	924.3	5.3	1.0	1,965.5
Event[1]	Oct 23-25, 2012	614.4	3.8	1.0	17,022.6
Low flow[2]	Oct 25-30, 2012	490.8	2.6	1.6	553.7
Event[2]	Oct 30 - Nov 6, 2012	2,562.0	20.9	6.4	14,261.5
Low flow[1]	Nov 6-12, 2012	362.4	0.6	0.8	56.5
Event[2]	Nov 12-14, 2012	465.6	2.6	0.6	35.4
Low flow[1]	Nov 14-29, 2012	732.3	1.0	1.6	108.9
Event[2]	Nov 29 - Dec 3, 2012	786.9	18.8	47.6	25,061.3
Event[1]	Dec 3-7, 2012	759.6	13.5	33.8	21,514.4
Event[2]	Dec 7-23, 2012	2,868.0	22.9	23.0	6,398.5
Low flow[2]	Dec 23, 2012 - Jan 10, 2013	1,257.4	2.0	2.7	196.6
Event[1]	Jan 11-13, 2013	1,660.9	6.1	101.0	67,225.8
Low flow[2]	Jan 14-28, 2013	1,370.4	10.1	12.5	4,532.3
Event[1]	Jan 29 - Feb 5, 2013	1,975.9	53.0	151.5	131,755.6
Low flow[2]	Feb 5-19, 2013	929.1	3.6	4.9	658.1
Event[2]	Feb 19 - Mar 1, 2013	1,606.1	14.0	18.8	31,373.3
Low flow[1]	Mar 1-8, 2013	617.7	2.2	2.3	459.6
Event[1]	Mar 8-18, 2013	2,426.7	55.1	70.2	78,583.1
Event[2]	Mar 18 - Apr 8, 2013	1,467.9	4.6	7.1	1,811.3
Event[1]	Apr 8-15, 2013	2,817.9	47.5	201.0	151,926.7
Low flow[2]	Apr 15-18, 2013	427.5	1.3	2.4	807.4
Event[1]	Apr 18-29, 2013	2,322.1	23.5	65.5	53,792.2
Low flow[1]	Apr 29 - May 28, 2013	875.2	0.3	2.5	755.2
Event[1]	May 28 - Jun 5, 2013	2,566.7	4.6	26.1	29,385.1
Low flow[2]	Jun 5-10, 2013	258.9	0.5	0.9	169.2
Event[1]	Jun 10-11, 2013	65.5	0.1	0.5	298.7
Event[2]	Jun 11-18, 2013	763.3	1.1	4.6	2,320.9
Low flow[1]	Jun 18 - Jul 31, 2013	405.1	1.0	4.4	284.9
Event[1]	Jul 31 - Aug 6, 2013	605.6	7.8	66.5	68,612.5
Low flow[2]	Aug 6-30, 2013	281.1	2.8	5.6	2,509.0
Event[1]	Aug 30 - Sep 1, 2013	55.2	0.2	2.1	2,006.4
Low flow[1]	Sep 1-20, 2013	164.2	0.7	1.5	160.5
Event[1]	Sep 20-23, 2013	1,006.3	16.8	33.1	14,679.9
Low flow[2]	Sep 23-30, 2013	290.5	1.9	2.4	254.9
ANNUAL TOTAL		36,827	353	908	731,558

[1] Measured [2] Estimated

Table 4: Comparison of total mass load estimates and reference loads at GULGUL5 station in Gully Creek (October 1, 2012 – September 30, 2013). Note: Std. Dev. is standard deviation and Diff. (%) is the relative difference between the reference load and the estimated load.

Source	Load Estimation Method	Nitrate-Nitrogen + Nitrite-Nitrogen		Phosphate-Phosphorus		Total Phosphorus		Total Suspended Solids		Mean Diff. (%)	Std. Dev.
		Total Load (kg)	Diff. (%)	Total Load (kg)	Diff. (%)	Total Load (kg)	Diff. (%)	Total Load (kg)	Diff. (%)		
ABCA*	Numeric Integration[b] (Richards 1998)	36,827	-	353	-	908	-	731,558	-	-	-
Water Quality Analyser	Avg Load[a]	157,952	329	3,812	981	10,490	1,056	10,179,149	1,291	914	412
	Avg Load (lin interpolation)[e]	37,695	2	396	12	887	-2	700,681	-4	5	5
	Beale Ratio[c]	34,593	-6	835	137	2,311	155	2,116,965	189	122	80
	Conc Power Curve Fitting[d]	34,891	-5	349	-1	767	-16	590,184	-19	10	9
	Continuous Discharge Est[b]	36,808	0	333	-6	769	-15	635,111	-13	9	7
	Flow x Conc[a]	191,375	420	2,335	562	5,807	540	5,533,284	656	544	97
	Flow Stratified[b]	39,703	8	433	23	1,089	20	971,009	33	21	10
	Flow Weighted Conc[b]	34,673	-6	833	136	2,304	154	2,108,361	188	121	80
	Linear Interpolation[e]	36,559	-1	384	9	860	-5	679,549	-7	5	3
FLUX32	Avg Load[a]	157,952	329	3,812	981	10,490	1,056	10,179,149	1,291	914	412
	FWC[b]	34,673	-6	833	136	2,304	154	2,108,361	188	121	80
	FWC IJC[c]	34,593	-6	835	137	2,312	155	2,117,078	189	122	80
	C/Q Reg1[d]	35,948	-2	195	-45	481	-47	221,380	-70	41	28
	C/Q Reg2(VarAdj)[d]	35,232	-4	360	2	908	0	489,433	-33	10	16
	C/Q Reg3(daily)[d]	42,144	14	503	43	1,102	21	919,740	26	26	12
WISKI	Avg Linear Interpolation[e]	36,455	-1	384	9	860	-5	678,500	-7	6	3
PCSWMM	Hydrologic Process Model	38,650	5	316	-10	4,368	381	880,700	20	104	185

* Reference load
[a] Calculation by averaging technique
[b] Calculation by integration technique
[c] Calculation by ratio technique
[d] Calculation by regression technique
[e] Calculation by interpolation technique

Water Quality Indicator Spatial and Temporal Patterns

Once the "best" load estimation model was determined, annual mass load, flow-weighted mean concentration, and mass export were calculated for four water quality indicators (nitrate-nitrogen, phosphate-phosphorus, total phosphorus, and total suspended solids) in WQA.

In all five watersheds, flow-weighted mean TP and nitrate-nitrogen (nitrate-N) concentrations (Figure 2 and Appendix E) exceeded concentrations that are considered to minimize eutrophication: the Provincial Water Quality Objective for TP (0.03 milligrams per litre; OMOEE 1994) and a concentration identified by the Canadian Council of Ministers of the Environment for nitrate-N (0.9 milligrams per litre; CCME 2012). Median flow-weighted mean TP concentrations were approximately 0.15 milligrams per litre for all watersheds, excluding Trick's Creek, which had a median concentration of 0.06 milligrams per litre. The mean TP concentration for South Pine in 2013 was likely over-estimated due to that site having only been sampled for two events, which happened to be the largest events of the year.

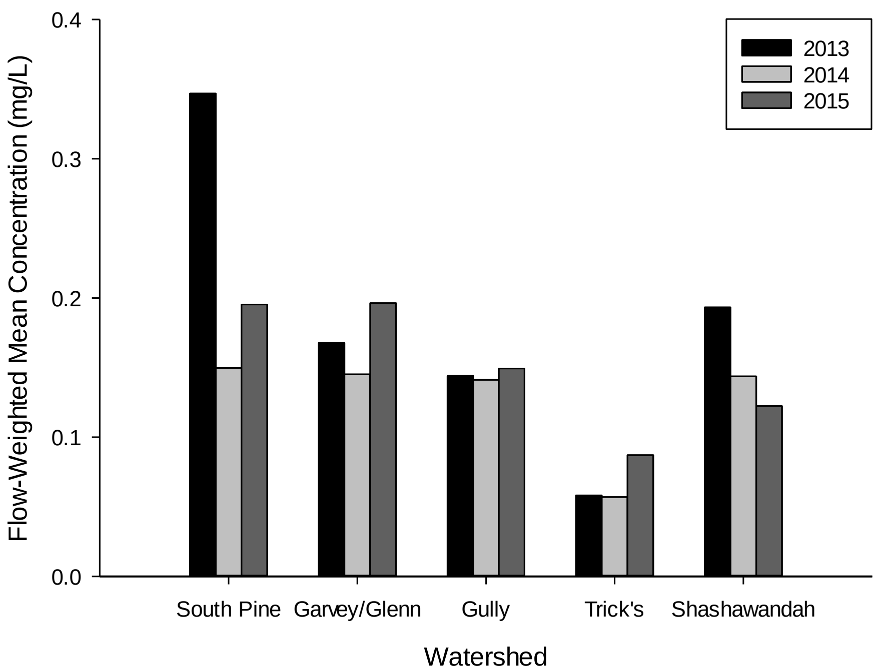

Figure 2: Annual flow-weighted mean total phosphorus concentrations in the Healthy Lake Huron watersheds.

Mass export coefficients for total phosphorus in the priority watersheds were consistent with other streams in Southwestern Ontario (Table 5). The mean TP export coefficient for the five priority watersheds was 0.85 kilograms per hectare, ranging from 0.34 kilograms per hectare at Trick's Creek during the 2013 water year to 1.53 kilograms per hectare at Gully Creek during the 2014 water year (Figure 3). Mass export coefficients (as well as loads) tend to be influenced by total flow volume from year to year, which explains why larger loads were observed during years with higher total flow volumes and smaller loads occurred during years with lower total flow volume.

Table 5: Annual total phosphorus (TP) export coefficients in agricultural, urban, and forested tributary catchments in Southwestern Ontario.

Land Use Type	Area	Mean (and Range) of TP Export Coefficient (kg/ha/year)	Reference
Agricultural	Lake Huron Tributaries	0.85 (0.34 to 1.53)	This report
Agricultural	Southwestern Ontario	(0.10 to 1.50)	PLUARG 1978
Agricultural/Urban/Forest	Lake Simcoe Tributaries	0.36 (0.08 to 2.21)	LSRCA 2010
Agricultural	Southwestern Ontario	0.92 (0.20 to 1.89)	OMOE 2012
Agricultural/Urban	Hamilton, Ontario	0.87 (0.14 to 1.40)	Long *et al.* 2015

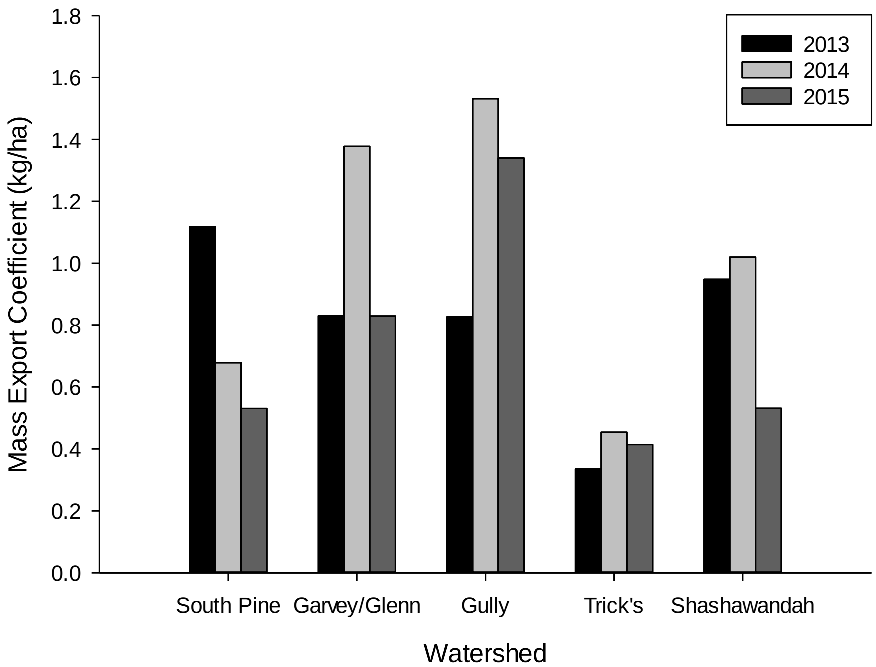

Figure 3: Annual total phosphorus mass export coefficients in the Healthy Lake Huron watersheds.

Annual flow-weighted mean concentrations and mass export coefficients were estimated for Gully Creek over a five-year period with the hope that patterns in water quality may be detected over a five-year period, rather than over the initial three-year interval. Total phosphorus flow-weighted mean concentrations ranged from 0.14 to 0.67 milligrams per litre during the five-year period (Figure 4), while export coefficients for TP ranged from 0.83 to 4.4 kilograms per hectare (Figure 5). It is important to note that a change of laboratory analysis method for total phosphorus occurred in 2013 at the MOECC. Similar patterns were observed for phosphate-P and TSS (which were not affected by the laboratory method change); however, due to the laboratory methodological changes for determining TP concentrations, the change in TP concentration in Gully Creek over this time period may not be realized.

The variability in mass export appears to be driven by changes in total flow volume in Gully Creek, particularly during the 2013 to 2015 water years (Figure 5).

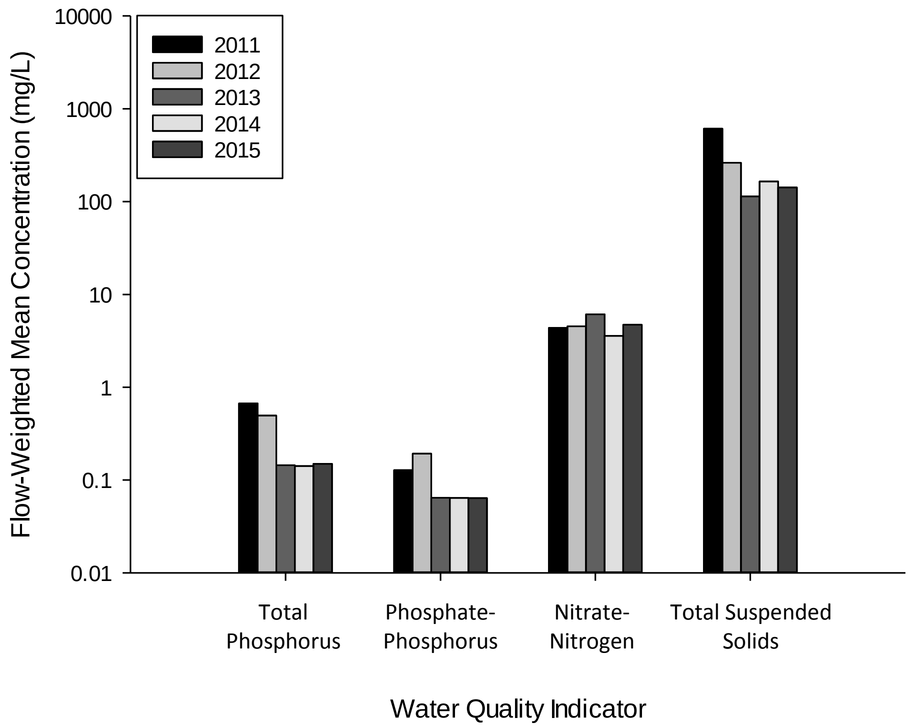

Figure 4: Annual flow-weighted mean concentrations (FWMC) in Gully Creek (October 1, 2010 – September 30, 2015). Notes: 1) Station GULGUL5 data were used to estimate FWMC for the 2012-2015 water years. Station GULGUL2 data were used for the 2011 water year. 2) A change of laboratory analysis method for total phosphorus occurred in 2013 at the Ministry of the Environment and Climate Change.

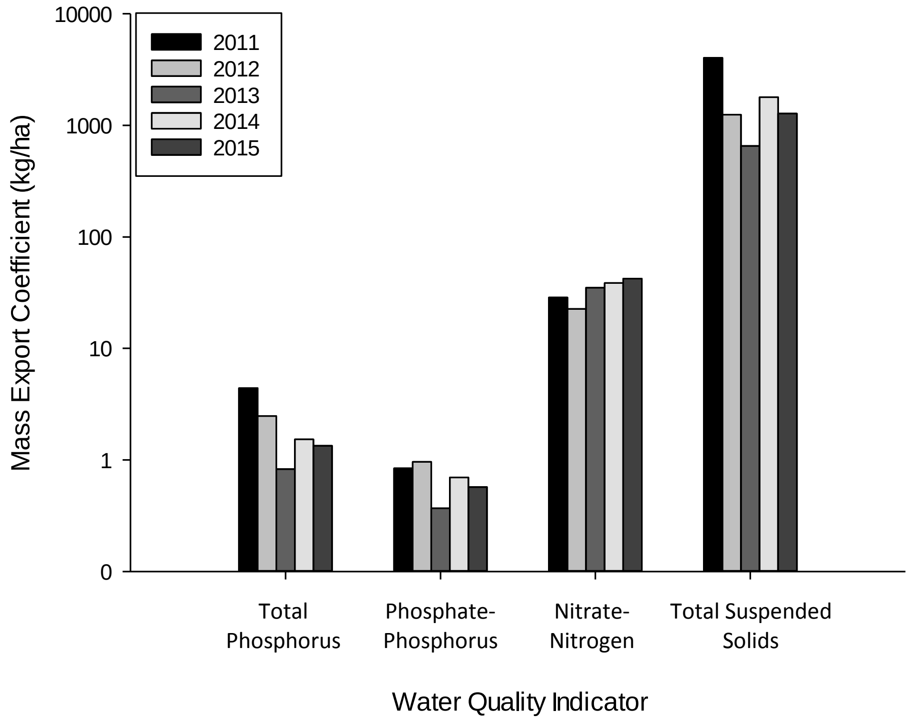

Figure 5: Annual mass export coefficients in Gully Creek (October 1, 2010 – September 30, 2015). Notes: 1) Station GULGUL5 data were used to estimate mass export coefficients for the 2012-2015 water years. Station GULGUL2 data were used for the 2011 water year. 2) A change of laboratory analysis method for total phosphorus occurred in 2013 at the Ministry of the Environment and Climate Change.

Seasonal Regression of Stream Flow and Pollutant Concentration

The seasonal relationship between event flow and pollutant concentration during the study period was not as consistent as we anticipated (Table 6). Some pollutant concentrations in Gully Creek appear to be influenced by flow regardless of season. For instance, TP and TSS had moderate to strong positive correlations with flow during seven of twelve seasons. Nitrate-N, on the other hand, was not associated with flow during eight of twelve seasons, and was negatively influenced by flow during three of twelve seasons.

The relationship between event flow and pollutant concentration for the four remaining watersheds was not strong. In fact, strong correlations between flow and concentration were uncommon during most seasons and years. For instance, TP and TSS were moderately to strongly related to flow during three of twelve seasons in the Garvey Creek/Glenn Drain, and during only one season in Trick's Creek.

Table 6: Summary of Pearson's correlation coefficients (R^2) comparing event flow and pollutant concentrations by seasonal flow regime in the Healthy Lake Huron watersheds. Note: NO_3-N is nitrate-nitrogen, PO_4-P is phosphate-phosphorus, TP is total phosphorus, and TSS is total suspended solids.

Water Year	Season	South Pine River				Garvey Creek/Glenn Drain				Gully Creek				Trick's Creek				Shashawandah Creek			
		NO_3-N	PO_4-P	TP	TSS	NO_3-N	PO_4-P	TP	TSS	NO_3-N	PO_4-P	TP	TSS	NO_3-N	PO_4-P	TP	TSS	NO_3-N	PO_4-P	TP	TSS
2013	Fall									0.69	0.75	0.92	0.83					0.46	0.15	0.14	0.21
	Winter	0.17	0.02	0.33	0.57	0.48	0.82	0.72	0.67	0.58	0.44	0.79	0.76	0.33	0.61	0.35	0.00	0.06	0.34	0.25	0.06
	Spring									0.14	0.59	0.20	0.04	0.02	0.33	0.00	0.00				
	Summer					0.03	0.78	0.59	0.03	0.02	0.16	0.93	0.94	0.02	0.78	0.07	0.00	0.04	0.54	0.00	0.03
2014	Fall	0.50	0.06	0.32	0.15	0.61	0.14	0.27	0.34	0.11	0.19	0.20	0.48	0.31	0.02	0.18	0.06	0.13	0.46	0.61	0.34
	Winter					0.49	0.00	0.51	0.34	0.66	0.68	0.82	0.46					0.71	0.12	0.10	0.58
	Spring	0.07	0.51	0.47	0.12	0.06	0.76	0.93	0.80	0.01	0.76	0.73	0.97	0.08	0.00	0.17	0.07	0.57	0.50	0.27	0.37
	Summer					0.00	0.22	0.12	0.26	0.00	0.36	0.79	0.76	0.03	0.64	0.40	0.06				
2015	Fall					0.25	0.48	0.73	0.63	0.02	0.89	0.92	0.79	0.04	0.25	0.35	0.67	0.16	0.11	0.10	0.00
	Winter	0.81	0.04	0.11	0.73	0.19	0.00	0.02	0.18					0.85	0.41	0.38	0.14	0.26	0.38	0.23	0.19
	Spring	0.33	0.37	0.16	0.02	0.01	0.03	0.12	0.05	0.04	0.24	0.45	0.66	0.30	0.64	0.84	0.87	0.01	0.05	0.02	0.15
	Summer									0.01	0.23	0.56	0.98	0.01	0.31	0.32	0.27				

Strong correlation ($R^2 = 0.7 \le x \le 1.0$)

Moderately strong correlation ($R^2 = 0.5 \le x \le 0.7$)

Moderately week correlation ($R^2 = 0.3 \le x \le 0.5$)

Weak correlation ($R^2 = 0.0 \le x \le 0.3$)

x Positive correlation

x Negative correlation

Insufficient data (n < 5)

Conclusions

This report has provided technical staff from the Healthy Lake Huron program with the opportunity to summarize the water quantity and quality data that has been collected in the priority watersheds along the south east shore of Lake Huron. Monitoring has been undertaken since June 2010 for Gully Creek and the fall of 2012 for four other watersheds. It is important to note that prior to the establishment of these priority areas, water samples were not collected with corresponding flow information and were not typically collected during run-off events. To evaluate the effectiveness of land-based BMPs, a water sampling program that reflects the times when water is running across the landscape must be used to obtain accurate estimates of pollutant loads. Furthermore, as pollutant concentrations are related to discharge condition, calculating the loads of various pollutants is necessary for evaluation. The requirements of sampling run-off events and the use of flow data in combination with water quality data represent a considerable change in human resources for monitoring programs that have been established by the technical staff in the Healthy Lake Huron.

As there are different approaches to combining discharge and concentration data to determine load, considerable effort was spent to evaluate different approaches. We chose to focus our evaluation on the data set collected for Gully Creek for the 2013 water year as it had the most robust water quality sampling effort. Evaluation of the different approaches to produce load values included the accuracy of the estimate compared to reference loads that were calculated with numeric integration. A second evaluation criterion was the ease of use of the model. Water quality models such as LOADEST or FLUX 32, designed to manipulate daily load data from large rivers, were too cumbersome to manipulate with a five minute discharge record. From our analysis (Table 4), with this particular data set, a linear interpolation method in WQA was best suited to calculate loads in the priority watersheds.

Typically concentrations of nutrients (nitrate-N and TP) in the five Lake Huron watersheds exceeded standards established to prevent eutrophication. Except for Trick's Creek, the five Lake Huron watersheds had similar total phosphorus concentrations and loads. Mean total phosphorus concentrations in the five watersheds were also consistent with other tributaries in southwestern Ontario. Other nutrient and suspended solid concentrations were more variable. All Lake Huron watersheds, except for Gully Creek, revealed weak relationships between flow and concentration. This indicates that in many cases the event mean concentrations may not be reliably predicted based on the size of an event. It was observed, however, that flow volume has an effect on load. For instance, total loads typically increased during years when the total volume of water carried by a stream was greater. Conversely, total loads decreased with a decline in total flow volume. This relationship between flow volume and load should be evaluated to see how it may impact our understanding of BMP effectiveness over time.

It is important to remember that the linear interpolation method was selected as a good method to estimate load where there is a robust number of samples (i.e., > 100 samples per year). It is also important to note that the linear interpolation method likely best approximates the calculation of the reference load that was used in this study. There are at least two important next steps. Firstly, because we tried to calculate an annual load, we used estimated loads as part of our reference load. We should remove the estimated portions and calculate a better reference load and retry our analysis. Secondly, some of the streams were not as well sampled (e.g., South Pine in 2013 had only 25 samples); it is possible that the linear interpolation method might not provide as good an estimate of load in this case. It will be helpful to "mine" well-sampled data sets from the five watersheds to determine if other approaches to estimating loads are better when there are fewer samples.

We have found that monitoring data alone are inadequate to explain variability in nutrient concentrations and loads. If data collection and analysis are to explain causal changes, the building of scenarios may be necessary. Hydrologic models can help to synthesize observations, analyze interactions amongst different processes and fill gaps in information. To date, two different models have been developed for the Gully Creek watershed: a Soil and Water Assessment Tool and a Rural Stormwater Management Model. The RSWMM was developed for the five priority watershed areas. The SWAT and the RSWMM also provide estimates of annual load and we used the output from those models to compare to the output from the water quality models. The SWAT seemed to provide a more accurate estimate of the 2013 TP load (Appendix D) than did the RSWMM estimate of the 2011 TP load (Table 4). However, the RSWMM applicability by agricultural industry partners might warrant more efforts to develop this model.

At this point, technical staff from the Healthy Lake Huron project have only been able to use the output from the SWAT model that was developed for the period 2002 to 2011. Due to the complexity of running SWAT for years that extended beyond the Watershed Based BMP Evaluation project time frame, 2012 to 2015, we continue to collaborate with researchers at the University of Guelph to support ongoing SWAT development. However, ongoing efforts to support watershed management agencies to collaborate with researchers will develop the potential for these models to help to explain changes in water quality with changes in land use and climate.

Next Steps

In summary, further analysis of this data set and some other data collected from south east shores Lake Huron tributaries would provide water managers with better approaches to understand water quality conditions. As discussed above, more analysis is required to:

1) ensure that the reference load is based only on sampled time periods;
2) mine data from the well-sampled data sets to determine the best method of calculating loads for steams that have <100 samples per year;
3) evaluate loadings into Lake Huron from a larger river system, such as the Bayfield River at Varna;
4) determine the relationship between total flow volume and load in the five watersheds;
5) determine seasonal and annual variations in pollutant loading to Lake Huron; and
6) allocate more staff time to using hydrologic process models (e.g., SWAT, PCSWMM) to explain water quality changes over time.

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Appendix A: Monitoring Stations

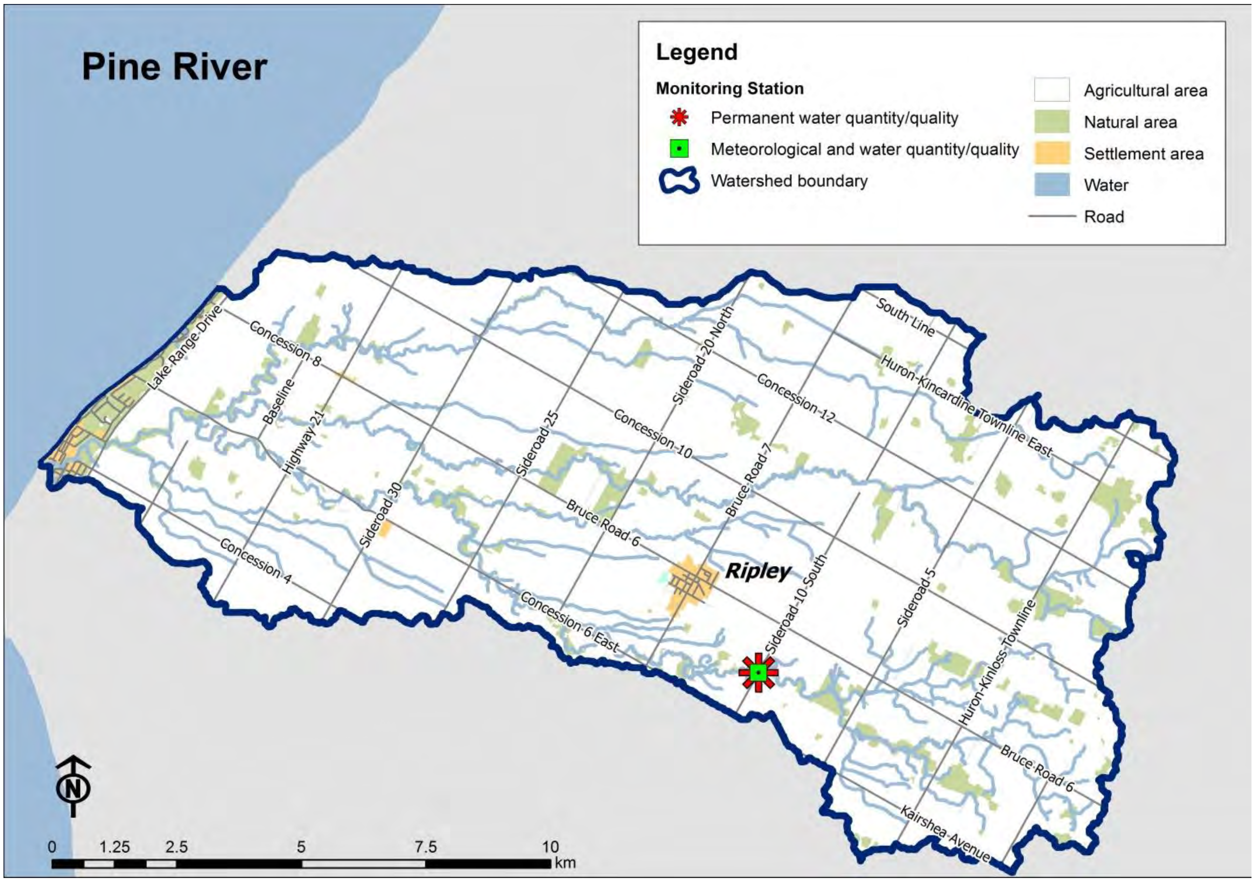

Figure A1: Location of the water quantity/quality sampling station (red) in the Pine River watershed.

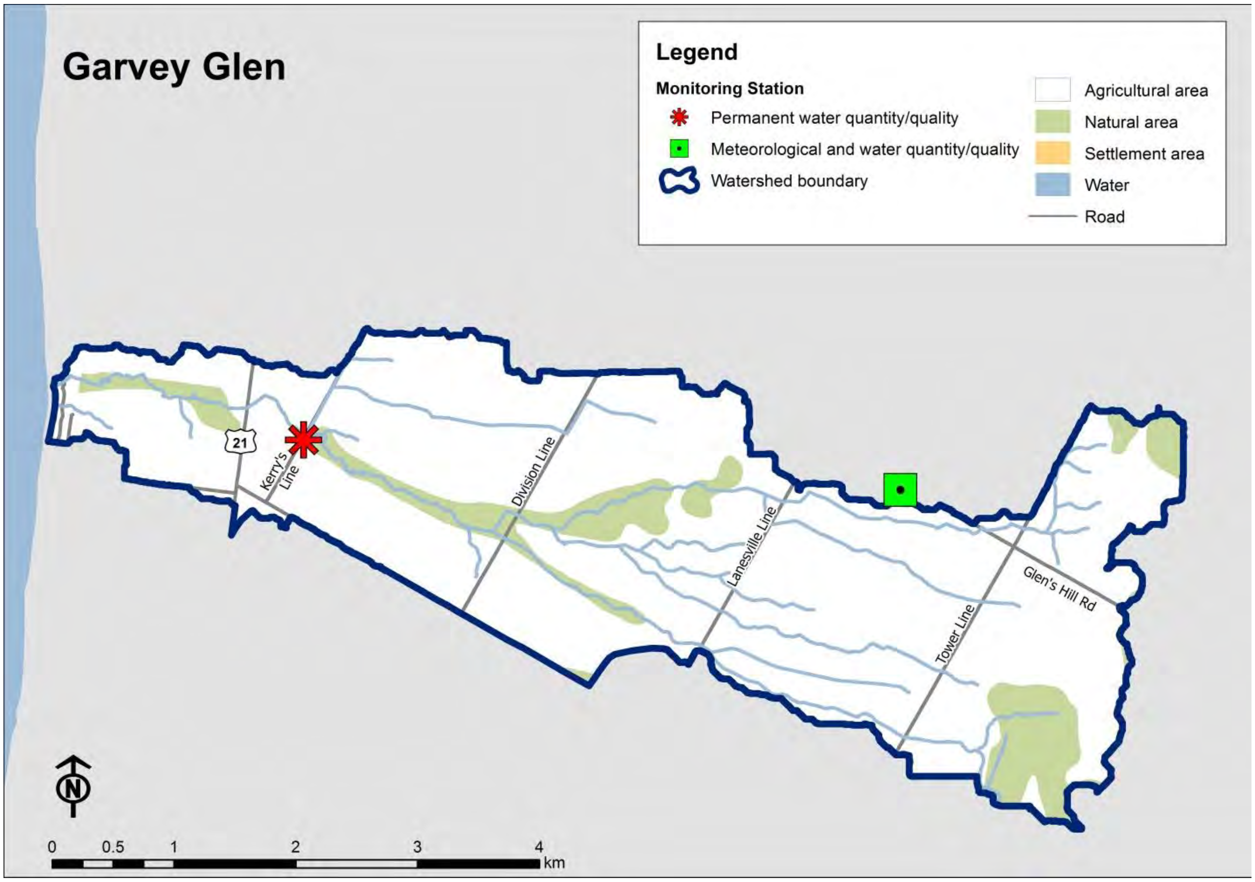

Figure A2: Location of the water quantity/quality sampling station (red) in the Garvey/Glenn Drain watershed.

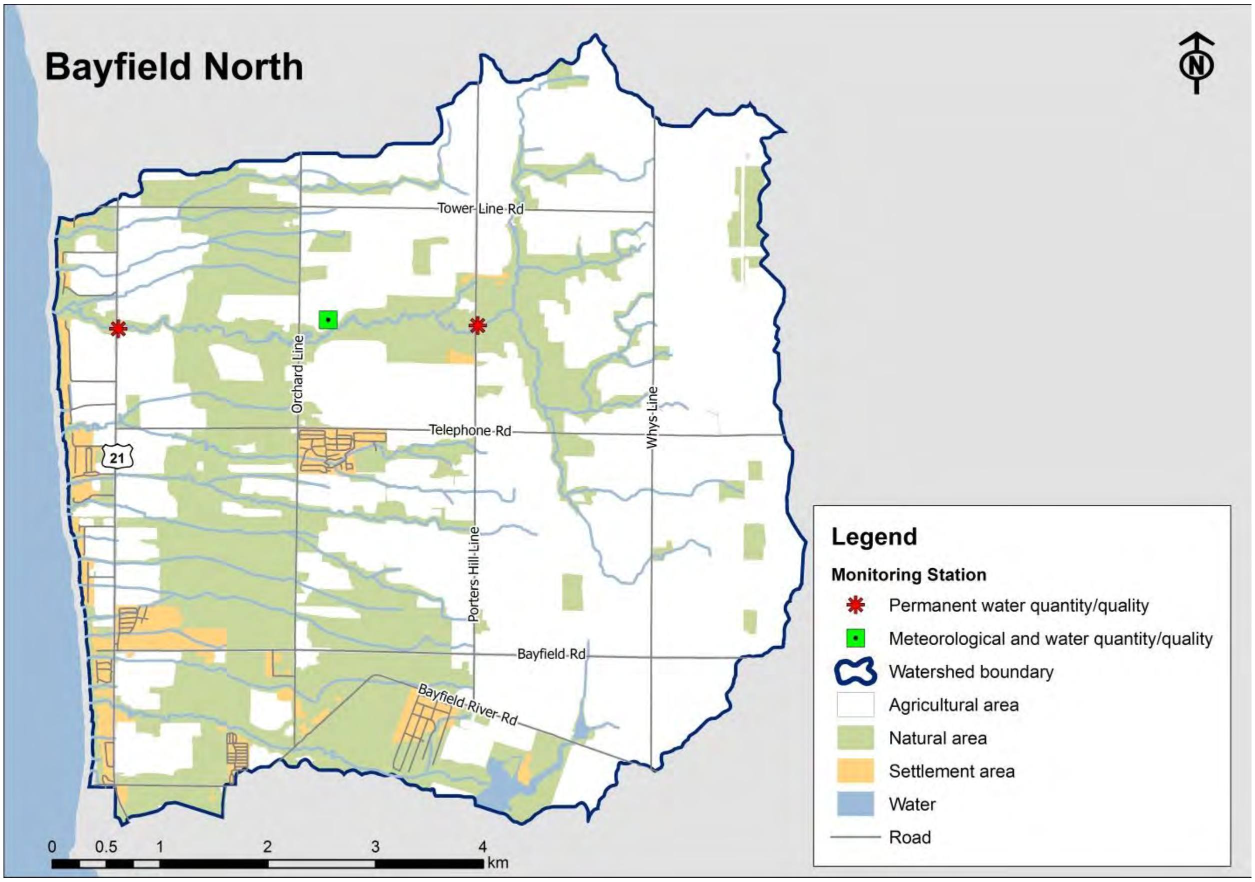

Figure A3: Location of the water quantity/quality sampling stations (red) in the Gully Creek watershed.

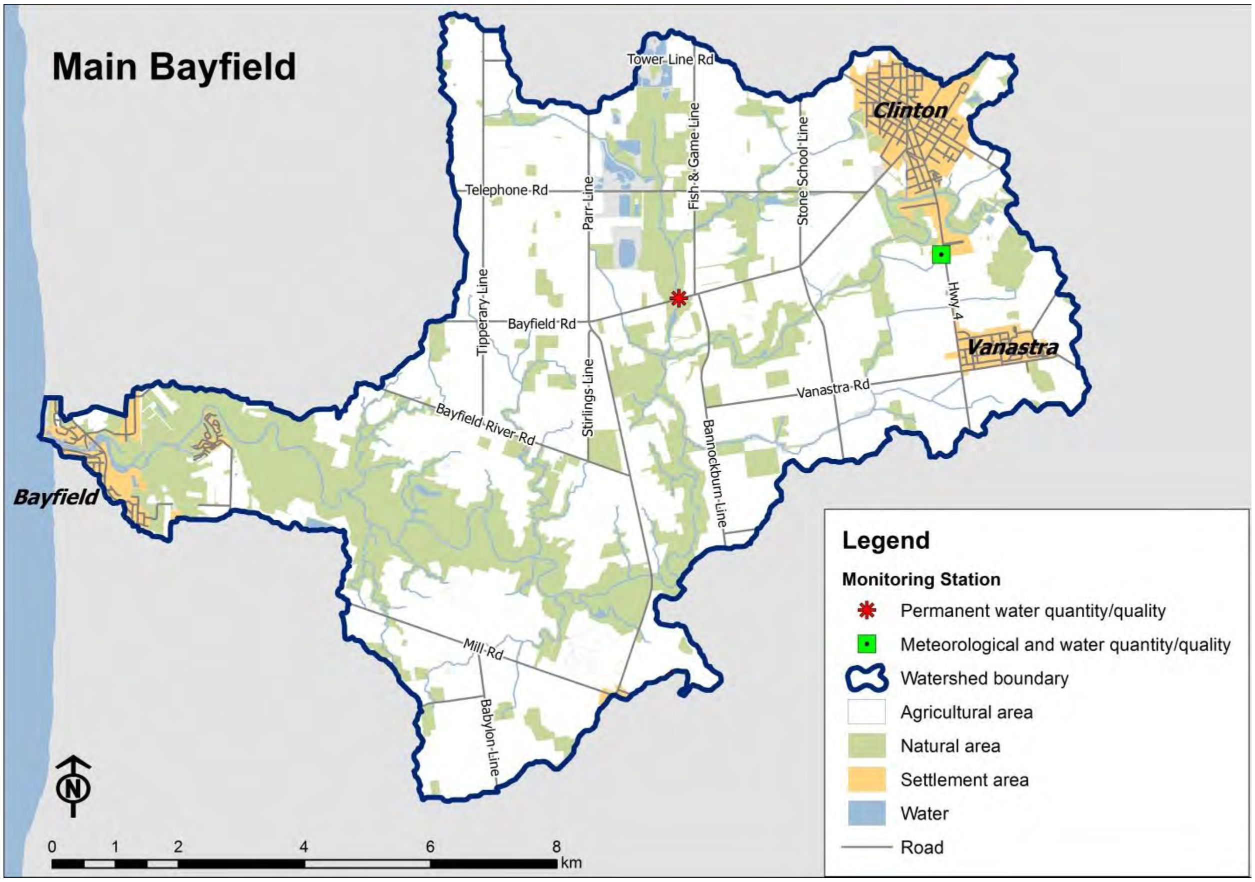

Figure A4: Location of the water quantity/quality sampling station (red) in the Trick's Creek watershed.

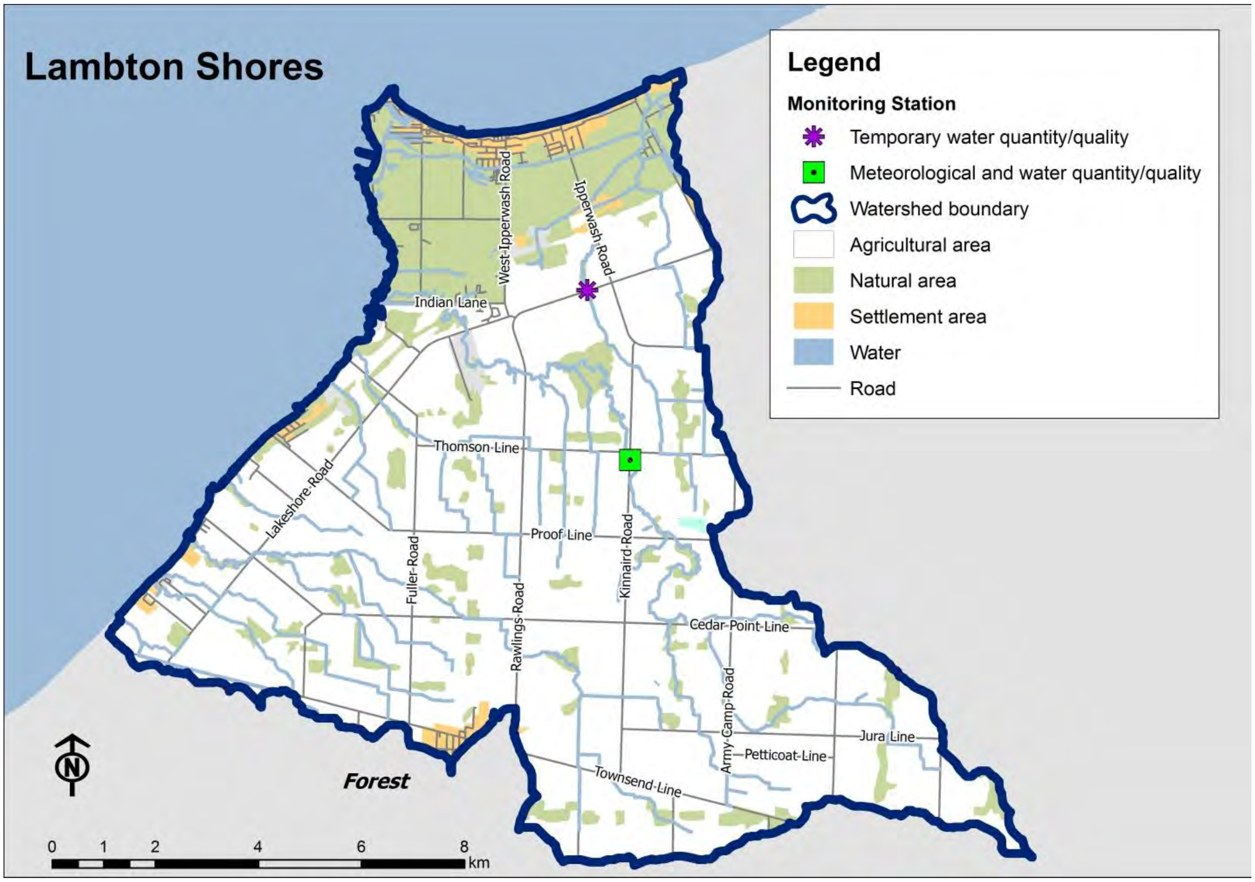

Figure A1: Location of the water quantity/quality sampling station (purple) in the Shashawandah Creek watershed.

Appendix B: Water Quality Analyser Load Estimation Equations[1]

Average Load Estimation Method

$$Load = k \sum_{i=1}^{n} \frac{c_i q_i}{n}$$

where

k is number of time intervals in period (*e.g.*, k=365)
n is total number of samples
i is number of a particular sample
c_i is i^{th} sampled concentration
q_i is i^{th} sampled discharge (flow)

Flow Weighted Concentration Method

$$Q \frac{\sum_{i=1}^{n} c_i q_i}{\sum_{i=1}^{n} q_i}$$

where

Q is total discharge for period
n is total number of samples
i is number of a particular sample
c_i is i^{th} sampled concentration
q_i is i^{th} sampled discharge (flow)

Linear Interpolation of Concentration Data Method

$$\sum_{j=1}^{n} \frac{c_j + c_{j+1}}{2} q_j$$

where

n is total number of samples
j is number of a particular sample
c_j is j^{th} sample concentration
q_j is inter-sample mean flow

[1]Equations were derived from Water Quality Analyser's User Manual. Note that some mathematical terms and symbols have not been defined. We contacted eWater (developer of WQA) for further information, but have not received a reply.

Flow Stratified Sampling Method

$$\sum_{j=1}^{n_s} \frac{N_j}{n_j} \left[\sum_{i=1}^{n_j} q_{ij} c_{ij} \right]$$

where

N_j is the number of time intervals in j^{th} stratum
q_i is i^{th} sampled discharge (flow)
c_i is i^{th} sampled concentration

Beale Ratio Estimator Method

$$Q \left(\frac{\bar{l}}{\bar{q}} \right) \left\{ \frac{1 + \frac{1}{N} \frac{\rho \sigma_L \sigma_Q}{\bar{l}_{\bar{q}}}}{1 + \frac{1}{N} \frac{\sigma_Q^2}{\bar{q}^2}} \right\}$$

where

Q is total discharge for period
$\bar{l}$ is average load for sample
$\bar{q}$ is average of N discharge measurements
$\boldsymbol{\sigma}_L$ is standard error of observed load
$\boldsymbol{\sigma}_Q$ is standard error of total discharge for period
$\boldsymbol{\rho}$ is coefficient correlation for L and Q

The term in curly brackets is the bias correction term. *N* is the expected population size (this is included in the calculation, to compensate for the effects of correlation between discharge and load).

Concentration Power Curve Method

$$c = aq^b$$

where

c is concentration
a is a coefficient
q is flow
b is a power coefficient

Appendix C: FLUX32 Load Estimation Equations[2]

Method 1: Average Load Estimation

$$Load\ (W_1) = k \sum_{i=1}^{n} \frac{c_i q_i}{n}$$

where

W_1 is Method 1 load estimate
k is number of time intervals in period (*e.g.*, k=365)
n is total number of samples
i is number of a particular sample
c_i is i^{th} sampled concentration
q_i is i^{th} sampled discharge (flow)

Method 2: Flow-Weighted Concentration

$$W_2 = \frac{W_1 Mean(Q_d)}{Mean\ (q_s)}$$

where

W_2 is Method 2 load estimate
W_1 is Method 1 load estimate (average load estimate)
Q_d is mean of daily flows
q_s is mean of sample flows

Method 3: Modified (Beale) Ratio Estimate

$$W_3 = W_2(1 + \frac{F_{wq}}{n})/(1 + \frac{F_q}{n})$$

where

W_3 is Method 3 load estimate
W_2 is Method 2 load estimate (flow-weighted concentration estimate)
$(1 + \frac{F_{wq}}{n})/(1 + \frac{F_q}{n})$ is the Beale ratio factor

[2]Equations were derived from FLUX32's FLUXWorkshop presentation. Note that some mathematical terms and symbols have not been defined.

Method 4: Regression (First-Order) Estimator

$$W_4 = W_1 \left[\frac{Mean(Q_d)}{Mean\ (q_s)}\right]^{b+1}$$

where

W_4 is Method 4 load estimate
W_1 is Method 1 load estimate (average load estimate)
Q_d is mean of daily flows
q_s is mean of sample flows
b is the slope of Ln(concentration) regressed on Ln(flow)

Method 5: Regression (Second-Order) Estimator

$$W_5 = \frac{W_4\left(1 + r\,F_Q\right)}{(1 + r\,F_q)}$$

where

W_5 is Method 5 load estimate
W_4 is Method 4 load estimate (first-order regression estimate)

Method 6: Regression Applied to Individual Daily Flows

$$W_6 = \sum_{i=1}^{n} exp\left[a + (b+1)\ln(Q_i) + \frac{SE^2}{2}\right]$$

where

W_6 is Method 6 load estimate
n is total number of samples
i is number of a particular sample
b is the slope of Ln(concentration) regressed on Ln(flow)

Appendix D: Load Estimation Performance of Soil and Water Assessment Tool (SWAT)

Table D.1: Comparison of total loads and export coefficients for GULGUL2 station in Gully Creek (October 1, 2010 – September 30, 2011).

Source	Load Estimation Method	Nitrate-Nitrogen*		Phosphate-Phosphorus		Total Phosphorus		Total Suspended Solids	
		Total Load (kg)	Export Coefficient (kg/ha)	Total Load (kg)	Export Coefficient (kg/ha)	Total Load (kg)	Export Coefficient (kg/ha)	Total Load (kg)	Export Coefficient (kg/ha)
Water Quality Analyser	Avg Load[a]	44,907	35	1,953	1.54	7,605	5.98	-	-
	Avg Load (lin interpolation)[e]	38,075	30	1,115	0.88	5,842	4.59	5,722,457	4,499
	Beale Ratio[c]	29,679	23	1,300	1.02	5,083	4.00	-	-
	Conc Power Curve Fitting[d]	26,822	21	818	0.64	4,058	3.19	-	-
	Continuous Discharge Est[b]	37,259	29	947	0.74	5,022	3.95	4,959,042	3,899
	Flow x Conc[a]	54,335	43	1,515	1.19	5,418	4.26	-	-
	Flow Stratified[b]	33,876	27	1,074	0.84	3,644	2.87	-	-
	Flow Weighted Conc[b]	29,774	23	1,295	1.02	5,042	3.96	-	-
	Linear Interpolation[e]	36,503	29	1,069	0.84	5,601	4.40	5,127,644	4,032
SWAT	Hydrologic Process Model	43,911	31	2,199	1.54	7,183	5.03	2,556,120	1,790

* Soil and Water Assessment Tool (SWAT) results represent Dissolved Nitrogen. (SWAT also produced values for Particulate Nitrogen and Total Nitrogen.)

[a] Calculation by averaging technique
[b] Calculation by integration technique
[c] Calculation by ratio technique
[d] Calculation by regression technique
[e] Calculation by interpolation technique

Appendix E: Mass Loads, Flow-weighted Mean Concentrations, and Mass Export Coefficients in Healthy Lake Huron Watersheds

Table E.1: Annual nitrate-nitrogen loads, flow-weighted mean concentrations, and export coefficients in the Healthy Lake Huron watersheds (October 1, 2012 – September 30, 2015).

Watershed	Nitrate-Nitrogen								
	2013 Water Year			2014 Water Year			2015 Water Year		
	Total Load (kg)	Export Coefficient (kg/ha)	Mean Concentration (mg/L)	Total Load (kg)	Export Coefficient (kg/ha)	Mean Concentration (mg/L)	Total Load (kg)	Export Coefficient (kg/ha)	Mean Concentration (mg/L)
South Pine	36,798	13.20	3.02	45,113	16.18	3.57	42,638	15.29	5.63
Garvey/Glenn	45,842	35.64	7.20	76,924	59.81	6.30	38,946	30.28	7.17
Gully	36,481	35.06	6.11	40,236	38.67	3.57	44,047	42.34	4.72
Trick's	48,678	23.01	4.00	68,215	32.25	4.04	36,230	17.13	3.60
Shashawandah	94,184	35.12	7.16	63,355	23.63	3.33	78,044	29.11	6.71

Table E.2: Annual phosphate-phosphorus loads, flow-weighted mean concentrations, and export coefficients in the Healthy Lake Huron watersheds (October 1, 2012 – September 30, 2015).

Watershed	Phosphate-Phosphorus								
	2013 Water Year			2014 Water Year			2015 Water Year		
	Total Load (kg)	Export Coefficient (kg/ha)	Mean Concentration (mg/L)	Total Load (kg)	Export Coefficient (kg/ha)	Mean Concentration (mg/L)	Total Load (kg)	Export Coefficient (kg/ha)	Mean Concentration (mg/L)
South Pine	663	0.24	0.05	567	0.20	0.04	192	0.07	0.03
Garvey/Glenn	658	0.51	0.10	1,591	1.24	0.13	655	0.51	0.12
Gully	384	0.37	0.06	725	0.70	0.06	595	0.57	0.06
Trick's	189	0.09	0.02	283	0.13	0.02	192	0.09	0.02
Shashawandah	1,271	0.47	0.10	2,002	0.75	0.11	697	0.26	0.06

Table E.3: Annual total phosphorus loads, flow-weighted mean concentrations, and export coefficients in the Healthy Lake Huron watersheds (October 1, 2012 – September 30, 2015).

Watershed	Total Phosphorus								
	2013 Water Year			2014 Water Year			2015 Water Year		
	Total Load (kg)	Export Coefficient (kg/ha)	Mean Concentration (mg/L)	Total Load (kg)	Export Coefficient (kg/ha)	Mean Concentration (mg/L)	Total Load (kg)	Export Coefficient (kg/ha)	Mean Concentration (mg/L)
South Pine	3,116	1.12	0.35	1,892	0.68	0.15	1,479	0.53	0.20
Garvey/Glenn	1,068	0.83	0.17	1,772	1.38	0.15	1,067	0.83	0.20
Gully	860	0.83	0.14	1,593	1.53	0.14	1,394	1.34	0.15
Trick's	709	0.34	0.06	961	0.45	0.06	876	0.41	0.09
Shashawandah	2,543	0.95	0.19	2,735	1.02	0.14	1,424	0.53	0.12

Table E.4: Annual total suspended solids loads, flow-weighted mean concentrations, and export coefficients in the Healthy Lake Huron watersheds (October 1, 2012 – September 30, 2015).

Watershed	Total Suspended Solids								
	2013 Water Year			2014 Water Year			2015 Water Year		
	Total Load (kg)	Export Coefficient (kg/ha)	Mean Concentration (mg/L)	Total Load (kg)	Export Coefficient (kg/ha)	Mean Concentration (mg/L)	Total Load (kg)	Export Coefficient (kg/ha)	Mean Concentration (mg/L)
South Pine	1,685,160	604.35	138.49	1,850,455	663.63	146.30	403,288	144.63	53.27
Garvey/Glenn	444,138	345.34	69.74	437,847	340.45	35.86	224,912	174.88	41.39
Gully	679,549	653.16	113.77	1,863,866	1,791.49	165.20	1,328,738	1,277.14	142.26
Trick's	430,357	203.43	35.37	625,818	295.83	37.07	1,015,831	480.18	101.00
Shashawandah	911,834	340.06	69.32	455,759	169.97	23.95	302,753	112.91	26.01